Development and qualification of S53 ultrahigh-strength corrosion resistant steel for cadmium replacement

JCAT

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Report Documentation Page

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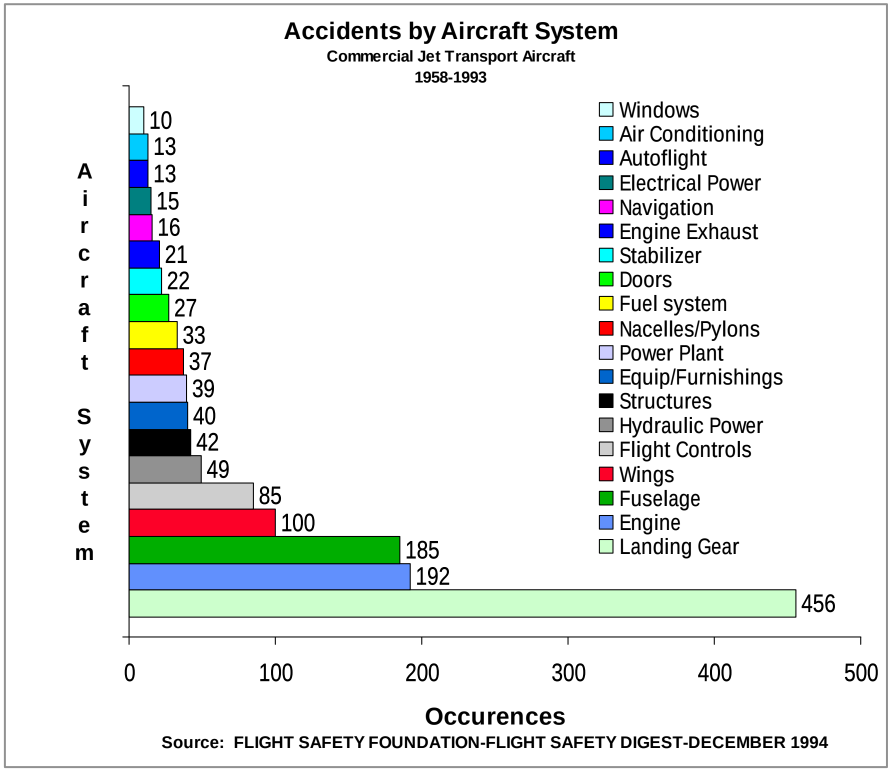
Drivers



SCC failure

HE failure

<u>Issues:</u>

- Over $200 million spent in LG per year
  - 80% corrosion related
- SCC failures
- Cad plating used to protect current steel known carcinogen (Hill AFB ~ 2000 lbs/yr)

<u>Benefits:</u>

- Dramatic reduction in LG cost (60%)
  - savings of $120 million per year
- Significant reduction in SCC failures
- Cadmium plating not required
- General corrosion mitigated
- 80% of Steel Condemnations Avoided

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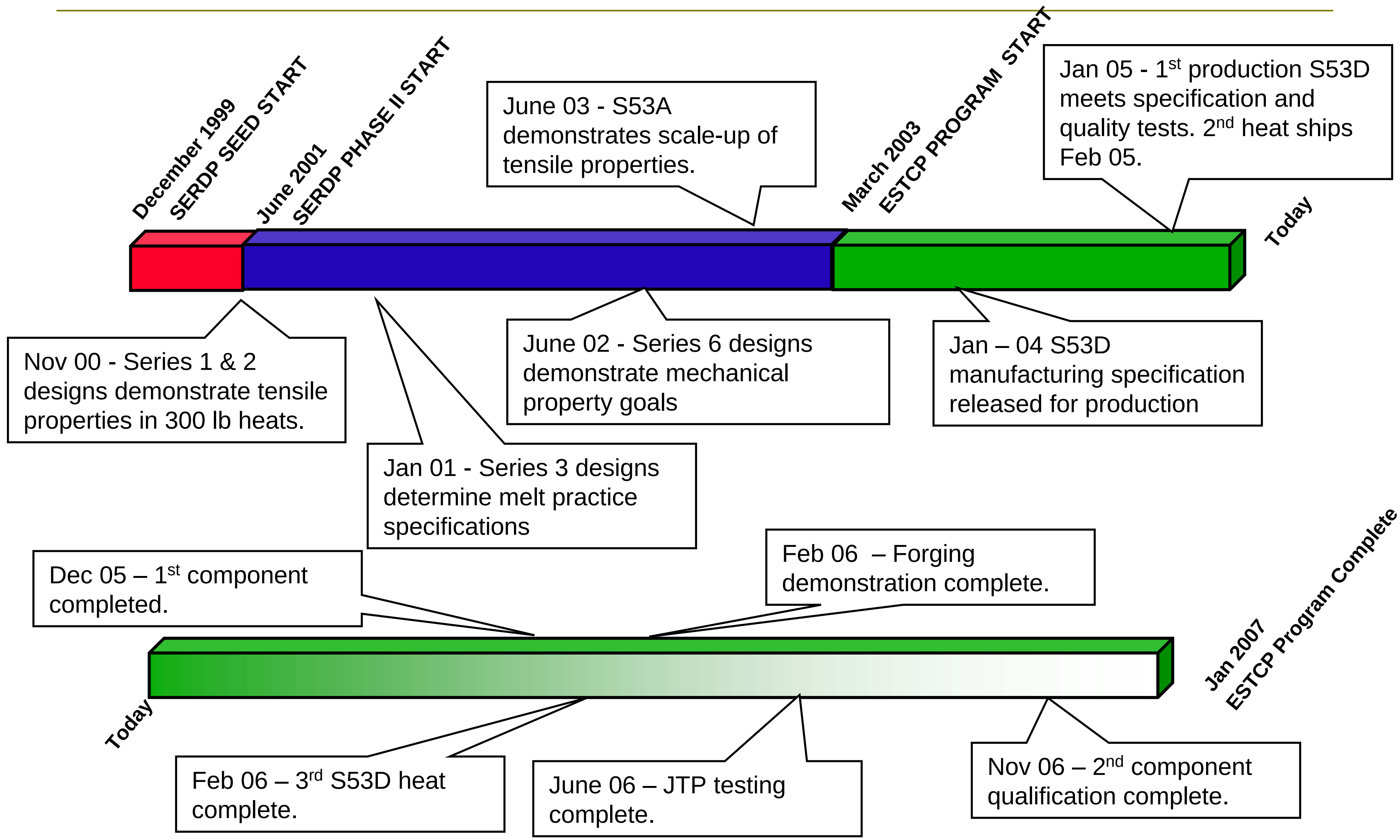
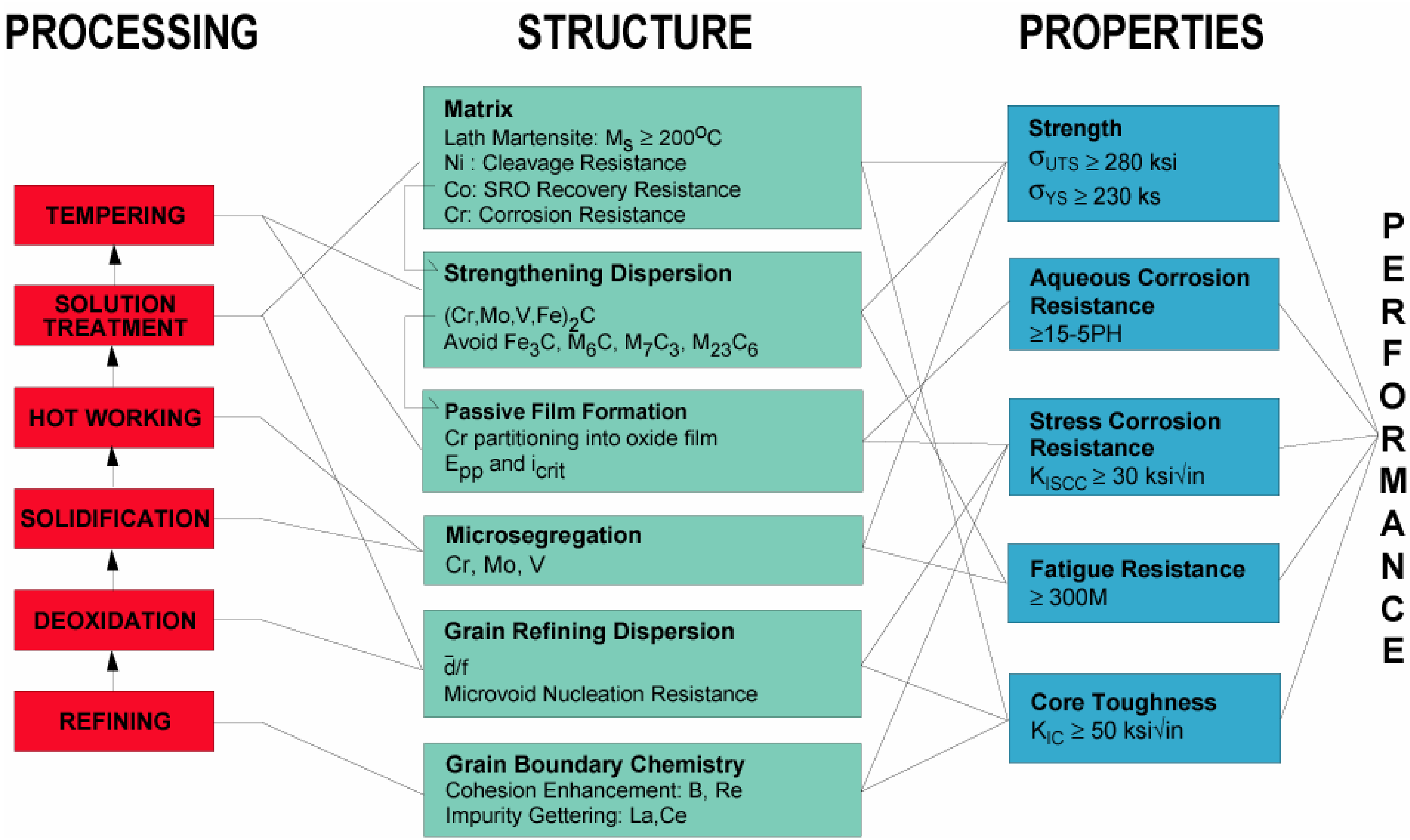
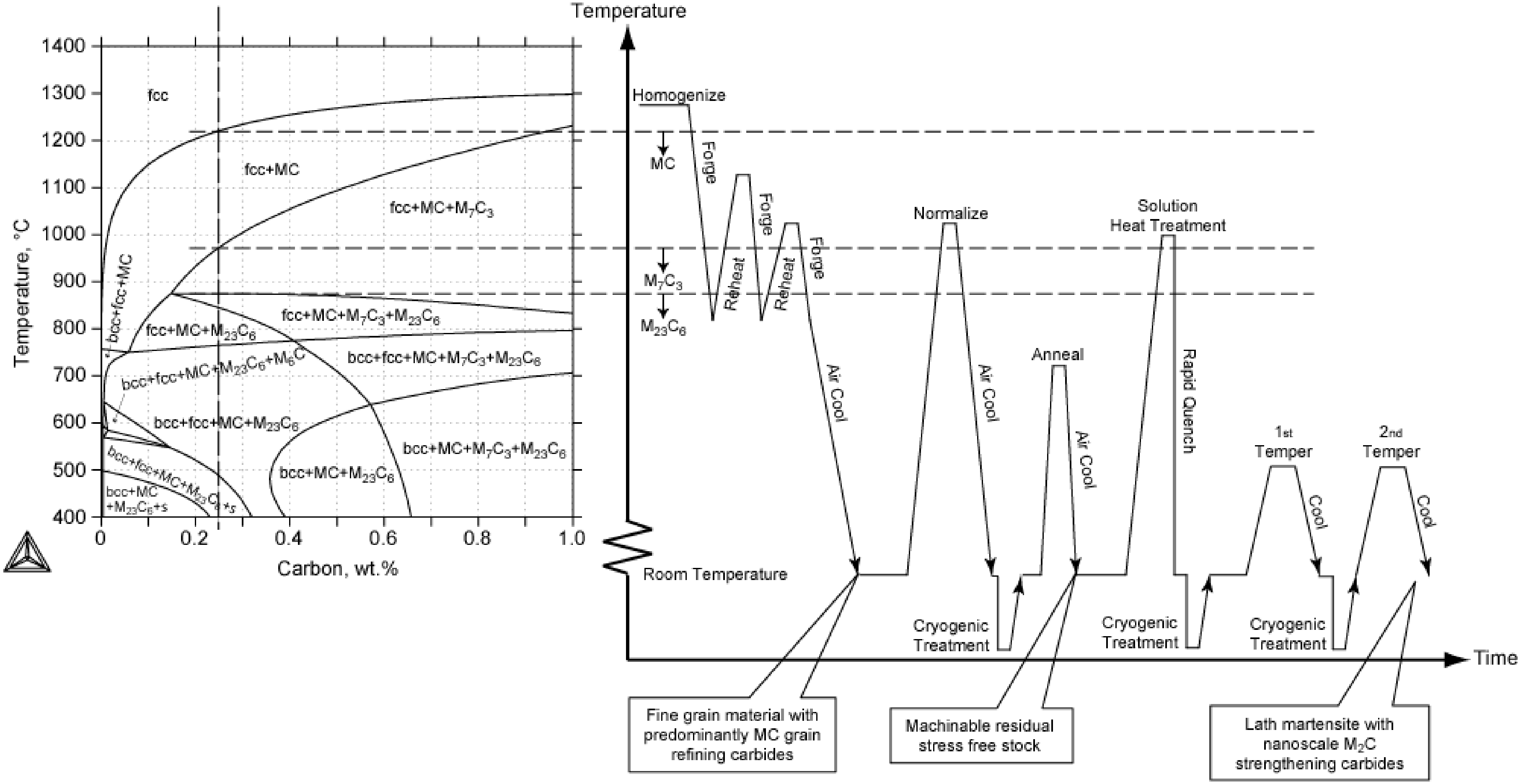
Milestones and Plans



S53 System Flow-Block Diagram



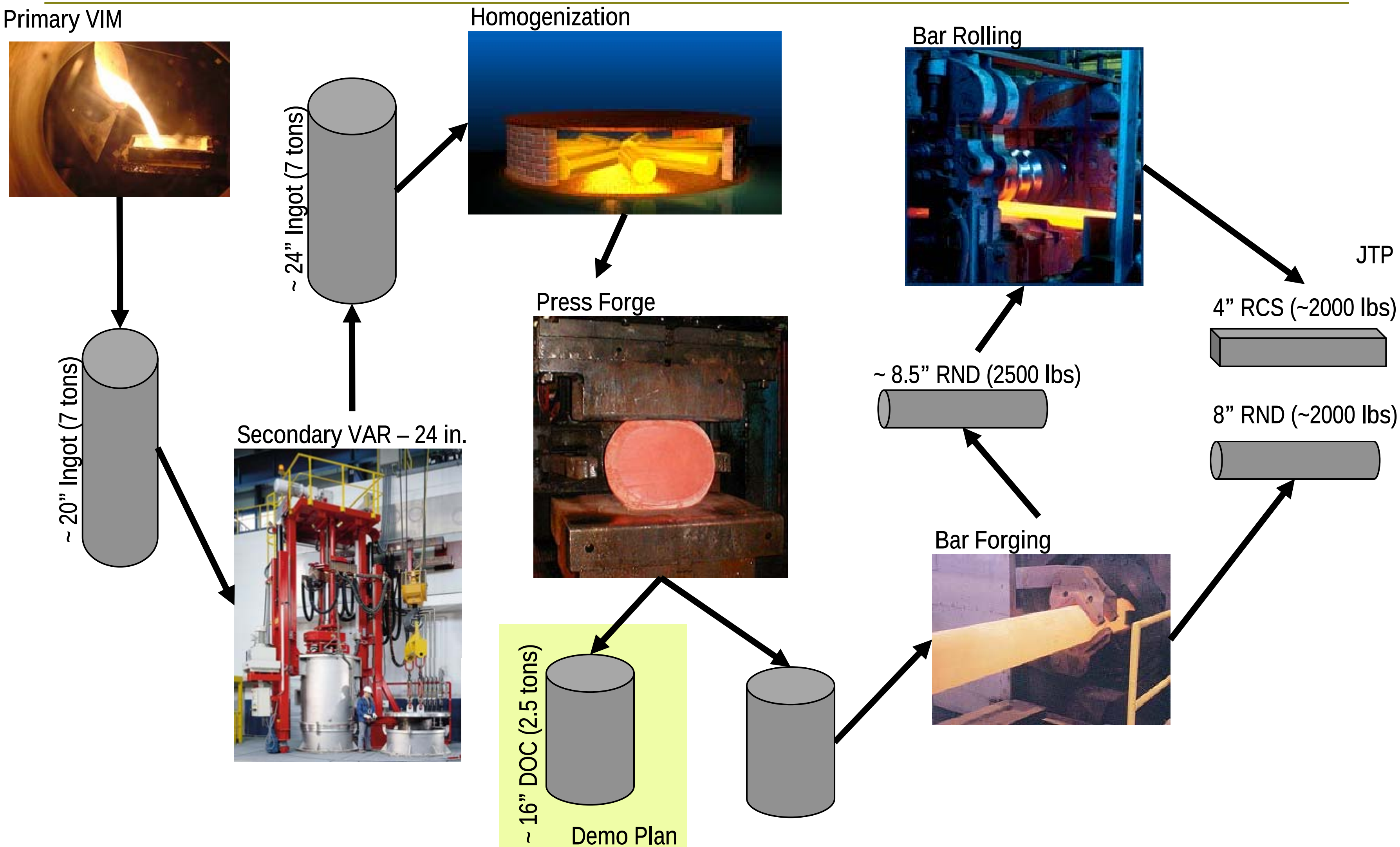
S53 Processing Schematic



ESTCP Program Objectives

- 3 Commercial scale heats
- Identify initial implementation components
- Qualification testing for AMS (S-basis) allowables
  - Execution of Joint Test Protocol (JTP)
  - Estimate MMPDS A & B-basis allowables by AIM
- Specifications for manufacturing process
  - Alloy Production
  - Forging
  - Rough Machining
  - Heat Treatment
  - Finish Machining/Surface Preparation
- Cost/Benefit Analysis
- Future Implementation Plan

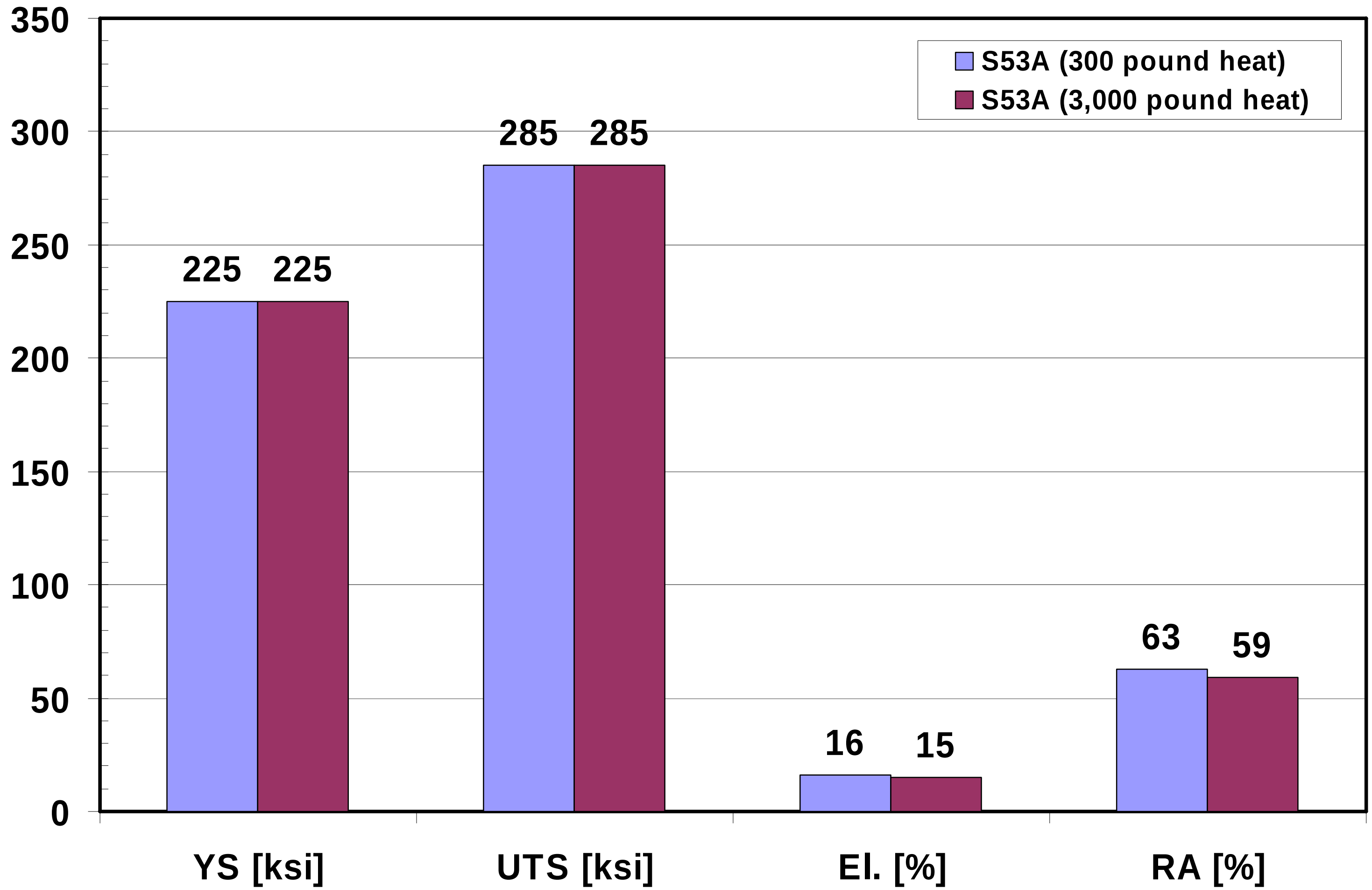
ESTCP Production Line-up



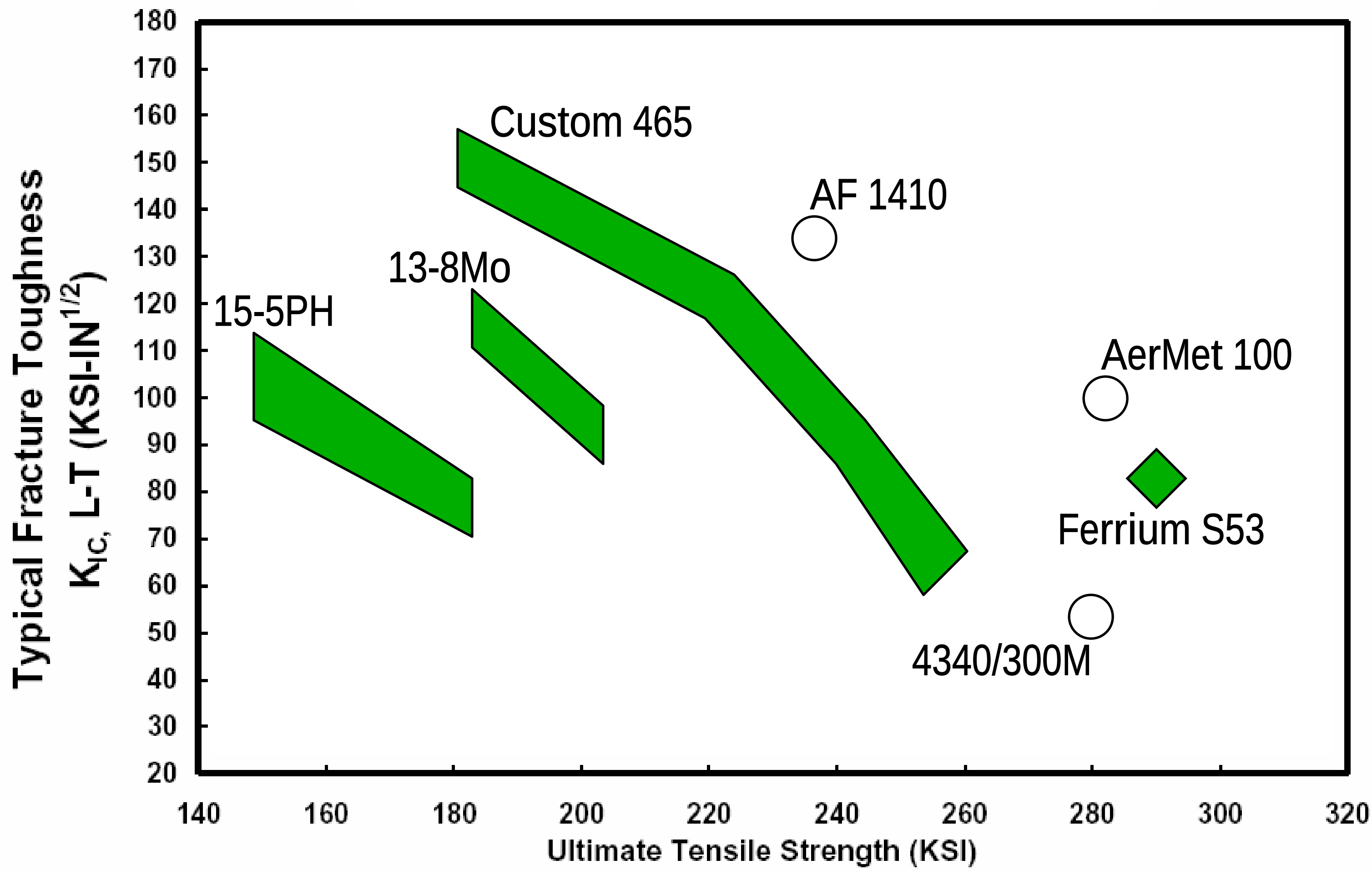
Joint Test Protocol

- **JTP**
  - **S53 validation**
    - **Producibility**
      - Full scale billet
      - Forging
      - Machining/grinding
      - Repairability
      - Coating/stripping
      - Fluid compatibility
      - NDI
    - **Properties**
      - Microstructure
      - Tensile
      - Hardness
      - Fracture strength K_{1c}
      - Charpy energy
    - **Performance**
      - Fatigue
      - Salt fog corrosion
      - Galvanic corrosion
      - Crevice corrosion
      - H embrittlement
      - SCC
  - **AIM validation**
    - Heat treatments
    - Microstructure
    - Tensile - Ftu
    - Fatigue Axial @ 10^5cycles, R=-1
    - Fracture CVN (-40F,RT), K_{IC}
    - Stress Corrosion K_{ISCC} 3.5%NaCl
    - Tensile - Fty

S53A Scale-up Properties



S53 Nanostructured UHS Stainless Results



Baseline Data

Ideal Heat Treatment Condition:

1100C 70 min + OQ + -78C 1 hr + AW(RT) + 505C 3 hrs + WQ

+ -78C 1 hr + AW(RT) + 492C 12 hrs + AC

209126

		0.2% YS	UTS	CVN	K_{IC}
8" round	Longitudinal	229.4	288.5	21	67
	Transverse	230.6	285.0	20	74
4" RCS	Longitudinal	229.8	285.3	19	

209193

8" round	Longitudinal	222.3	287	23	
4" RCS	Longitudinal	223.7	287.2	24	

Heat Treatment Conclusions

- Cryo not necessary to go all the way to liquid nitrogen

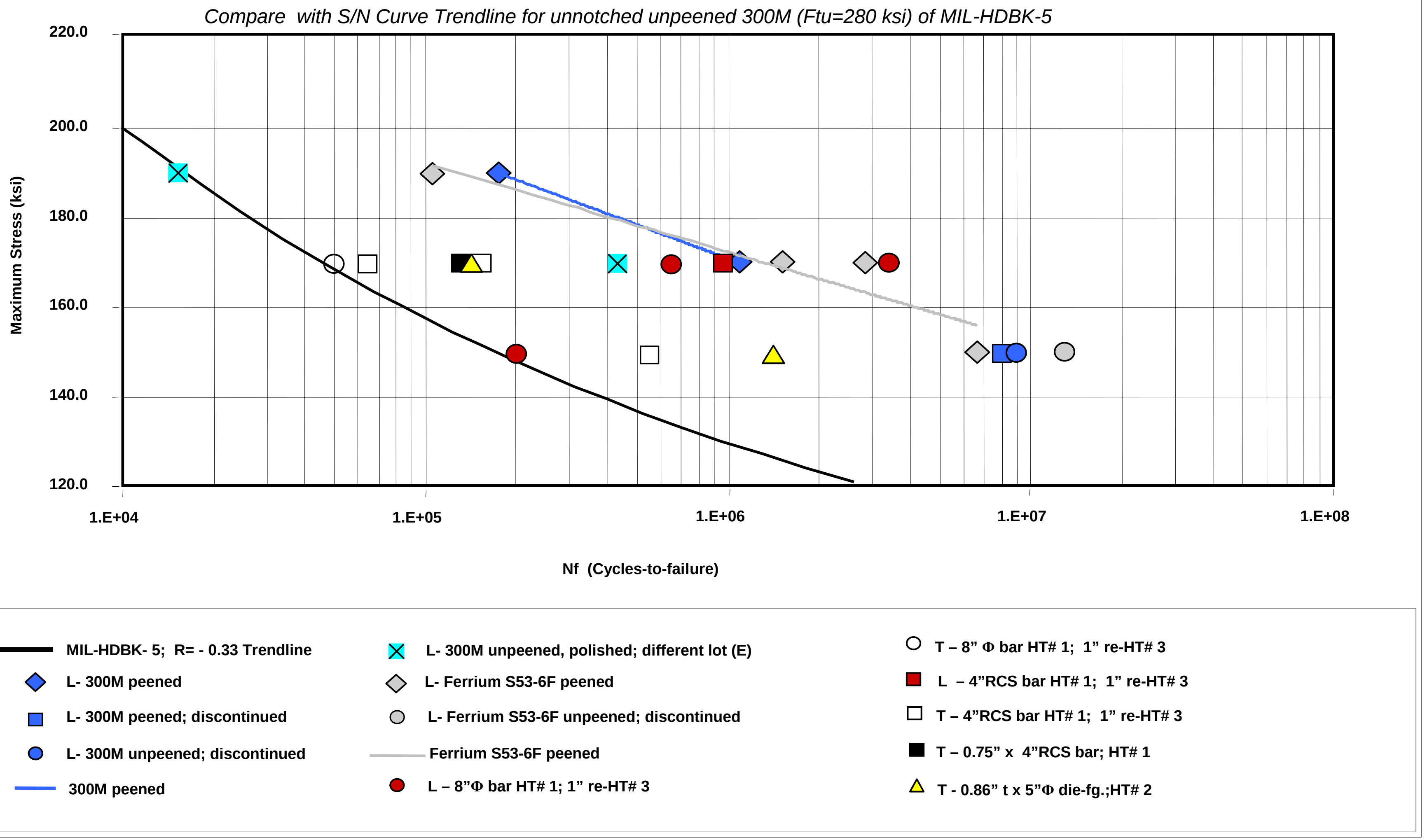
	0.2% YS	UTS	CVN
-78C	229.4	288.5	21
-196C	227.1	288.1	21

- Up to 8 hours after quench is acceptable before cryo-treatment

	0.2% YS	UTS	CVN
1 hour	225.1	287.9	22
5 hours	221.6	289.1	22
8 hours	231.3	284.4	20
24 hours	214.7	285.4	23

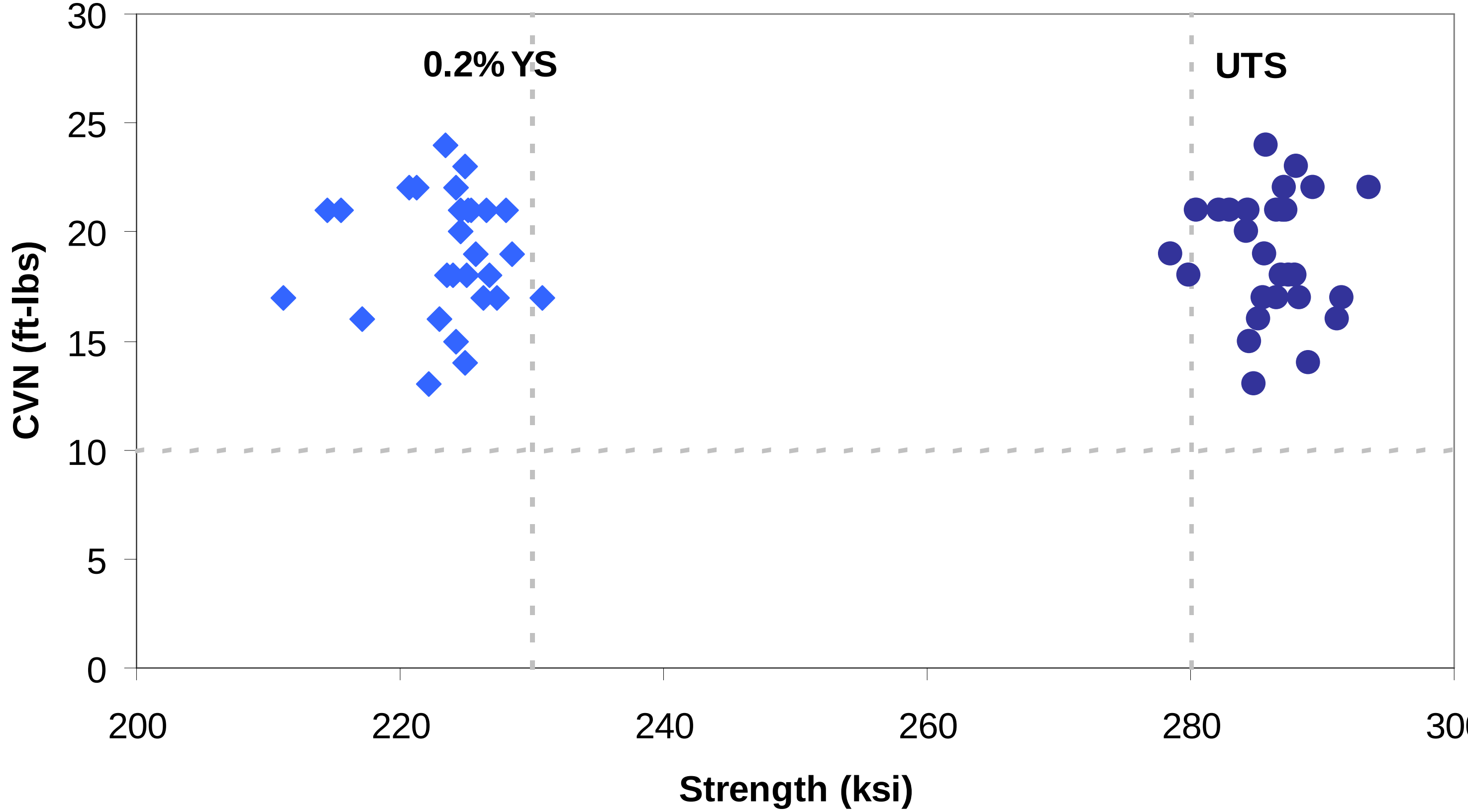
Successful scale-up: Fatigue of Production S53 alloy product forms from large Heat meet or exceed the 300M alloy fatigue trendline (L & T) of MIL-HDBK-5, and Longitudinal data matches L data of SERDP program's S53 alloy R&D small Heat

ESTCP Program on Ferrium S53 Corrosion Resistant Steel: R = - 0.33 Fatigue Data: for 300M (Su = 284 ksi) & S53-6F (Su = 291 ksi) (from 300 lbs Heat) of SERDP/2003 and production grade S53 (Su = 284 ksi) (from 10,000 lbs Heats).

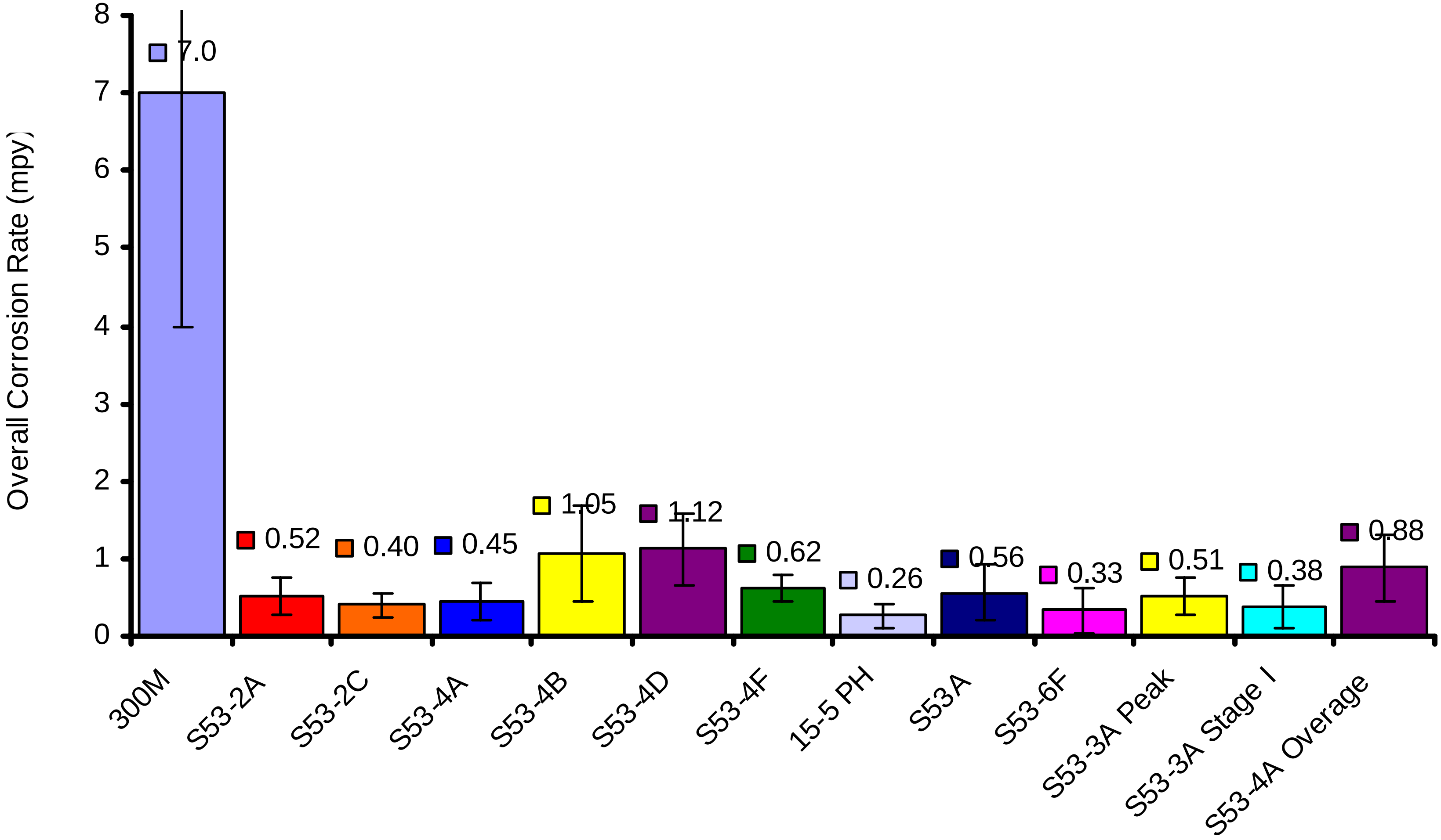


Sensitivity Analysis

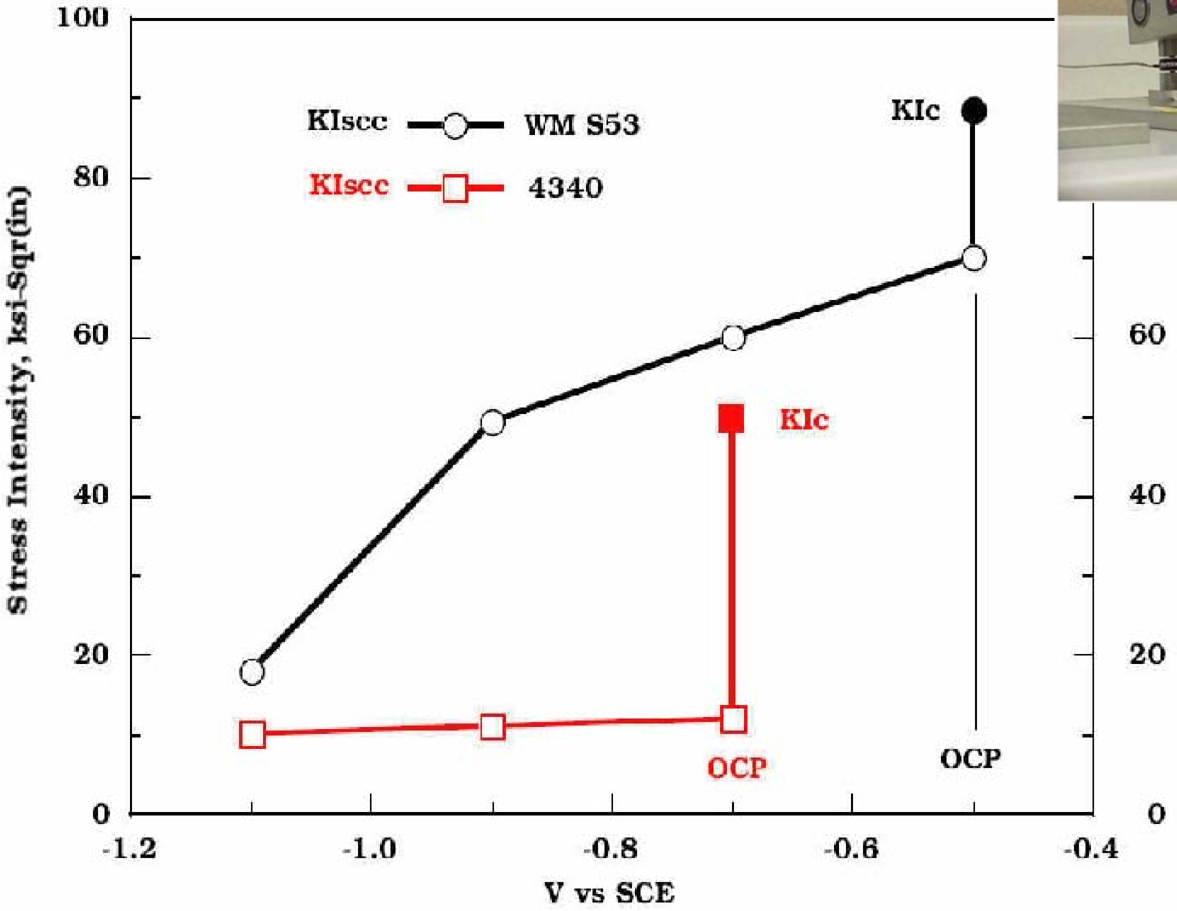
- +/- 7C in temperature (solution and tempering)
- +/- 30 minutes in time (solution and tempering)
- Represents 28 samples

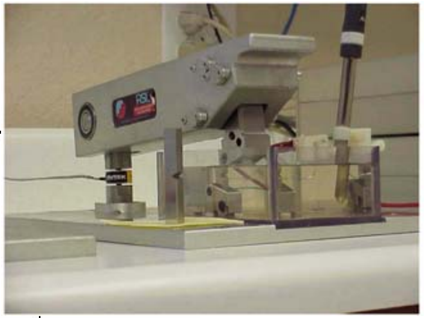


Corrosion Results from Anodic Polarization

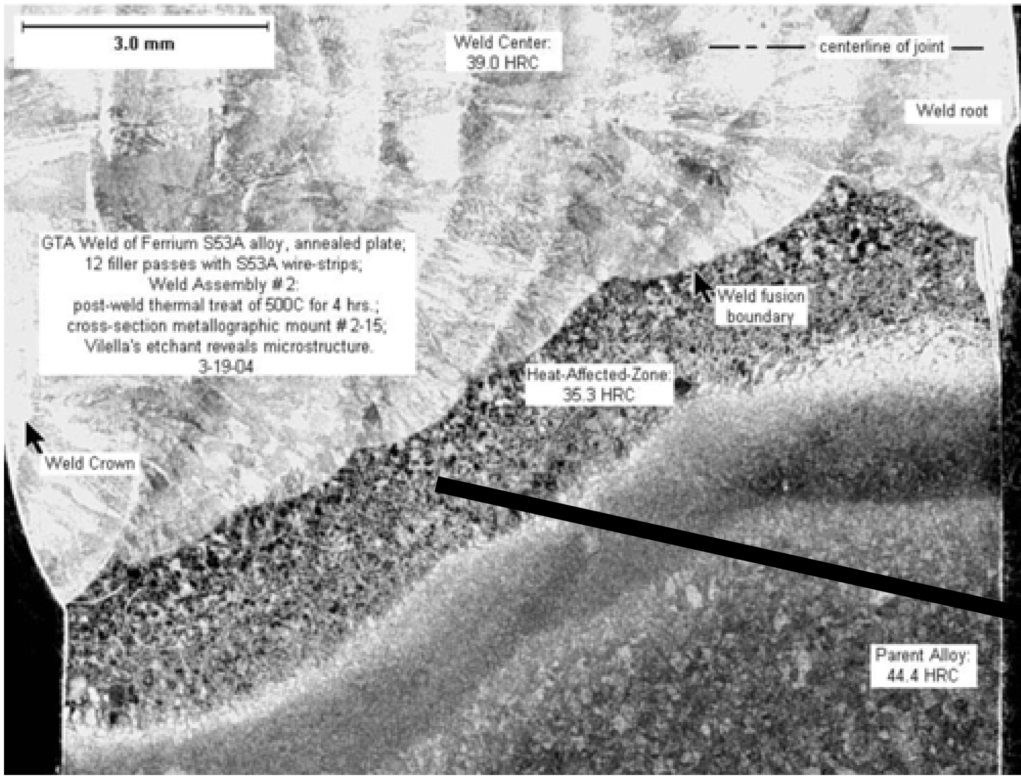


K_{ISCC} Results of Ferrium™ S53 vs 4340



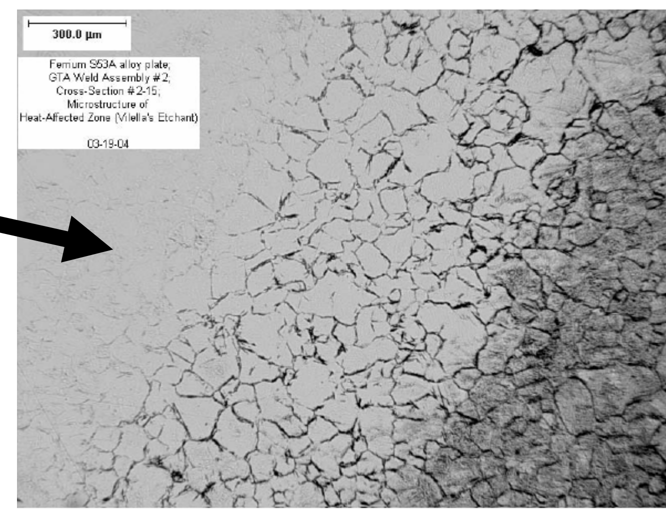


Weld Microstructure & Mechanical Properties



	Base Metal	*Weld Metal*
UTS (ksi)	276	275
YS (ksi)	226	220
Elong.%	15	9
CVN (ft-lbs.)	7	6

Study completed on S53A heat HC56 rejected for high N content.

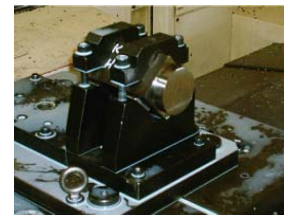


Annealed S53 Machinability Evaluations

- Turning annealed Ferrium S53 at 38 to 40 HRC is harder than turning 300M and AerMet 100 in the normalized and annealed condition.
- Ferrium S53 hardens during turning inducing an unusual wear of the inserts.
- Lower speed is needed to have a reasonable inserts wear.
- A very important deformation (TIR) was noted on a 7.75” bar (0.040”), even with a low speed, which is not acceptable.
- Feed is found to be the most critical parameter to decrease the deformation (TIR) of the bars. Feeds as low as 0.006” are needed (compared with 0.012” for Aermet 100).
- Very good finishes after turning could be reached (34 Ra) with the most performing inserts.
- S53D Spec. incorporates a cryo treatment to address high annnealed hardness and high work hardening rate – initial results are positive.


(a) cutting


(b) mill facing


(c) rounded end milling


(d) center drilling

P/N	Dimension	Number of parts	Interrupted turning	Continuous turning	Drilling	Tapping
SK-0110	3.5” x 3.5” x 7.75”	6	√	√		
SK-0112	3.5” x 3.5” x 7.75”	5	√	√		
SK-0113	3.5” x 3.5” x 23”	1	√	√		
SK-0114	3.5” x 3.5” x 7.75”	2	√	√		
SK-0115	3.5” x 3.5” x 7.75”	2	√	√		
SK-0116	3.5” x 3.5” x 17.3”	1			√	√
SK-0117	0.7” x 6” x 24”	2			√	

Production S53 Annealed Machinability

S53 Fully Hardened Machining Evaluations

Threaded S53 sample piece

P/N – Dia (inch)	Number of parts	Turning	Threading	Drilling
SK-0110 – 1.50	6	√ (parts prepared for the grinding trials)		
SK-0111 – 1.75	1	√		
SK-0112 – 3.00	5	√		
SK-0113 – 3.00	1	√		
SK-0114	2, three diam		√	
SK-0115 – 3.80	2	√		
SK-0117 – plate	2			√

Alloy	Insert	Speed (SFM) (1)	Infeed (Inch per Revolution)	Depth of cut (inch)	BNI/Finish (2)
300M	Carbide KC5010	160R	0.010	0.075	
		180F	0.008	0.030	
	Ceramics	550R/F	0.006	0.030	
Aermet 100	Carbide	N/A	N/A	N/A	
		160F	0.010	0.010	
Ferrium S53	Carbide KC5010/positive	150R	0.008	0.060	
	Carbide KC7310/positive	180F	0.008	0.015	A/58-64Ra
	Carbide KC5010 OR EH510Z/positive	120F	0.008	0.005	A/55-71Ra
	Carbide KC5010/positive	90F	0.006	0.015	A/15-16Ra

Grinding Results

- -S53 is very difficult induce grind damage
- -Grind burns could not be detected with a standard nital etch
- -New etchant needs to be developed

Forging Study

A10 MLG Piston

Kropp Forge

5/17/05

Takeaways:

•Forges easily

•Forges better than AerMet

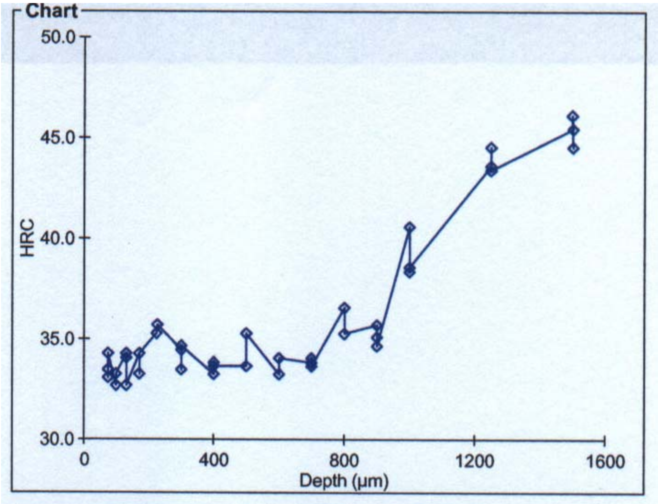
•Minimal (if any) change in mechanical properties

A10 Forging Characterization

- Mechanical

(Longitudinal Orientation)	0.2% YS	UTS	CVN
8" Bar Stock	229.4	288.5	21
A10 Forging	233.7	284.2	18

- Decarb



Decarb approximately 0.060” (1500 µm)

Demonstration Target Components

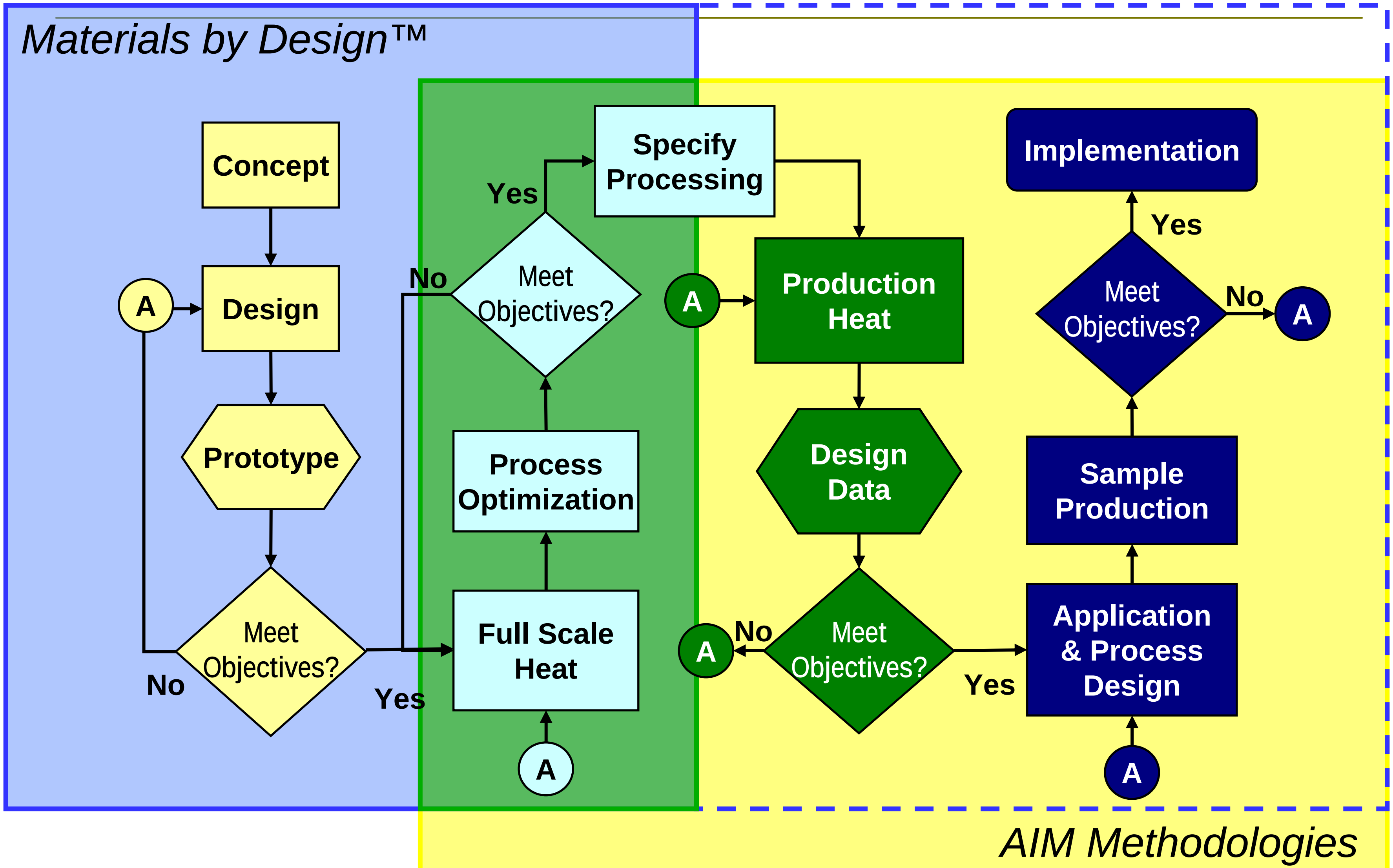
A-10 Main Landing Gear

•A-10 main landing gear piston (4330 – 240 ksi)
- •More complex loading
- •Forged component
- •Currently in production for spares

A-10 Nose Gear

•A-10 drag brace (300M - 270 ksi)
- •Simple tension loading
- •No forging required
- •Corrosion related failures

Accelerating the Materials Development Cycle



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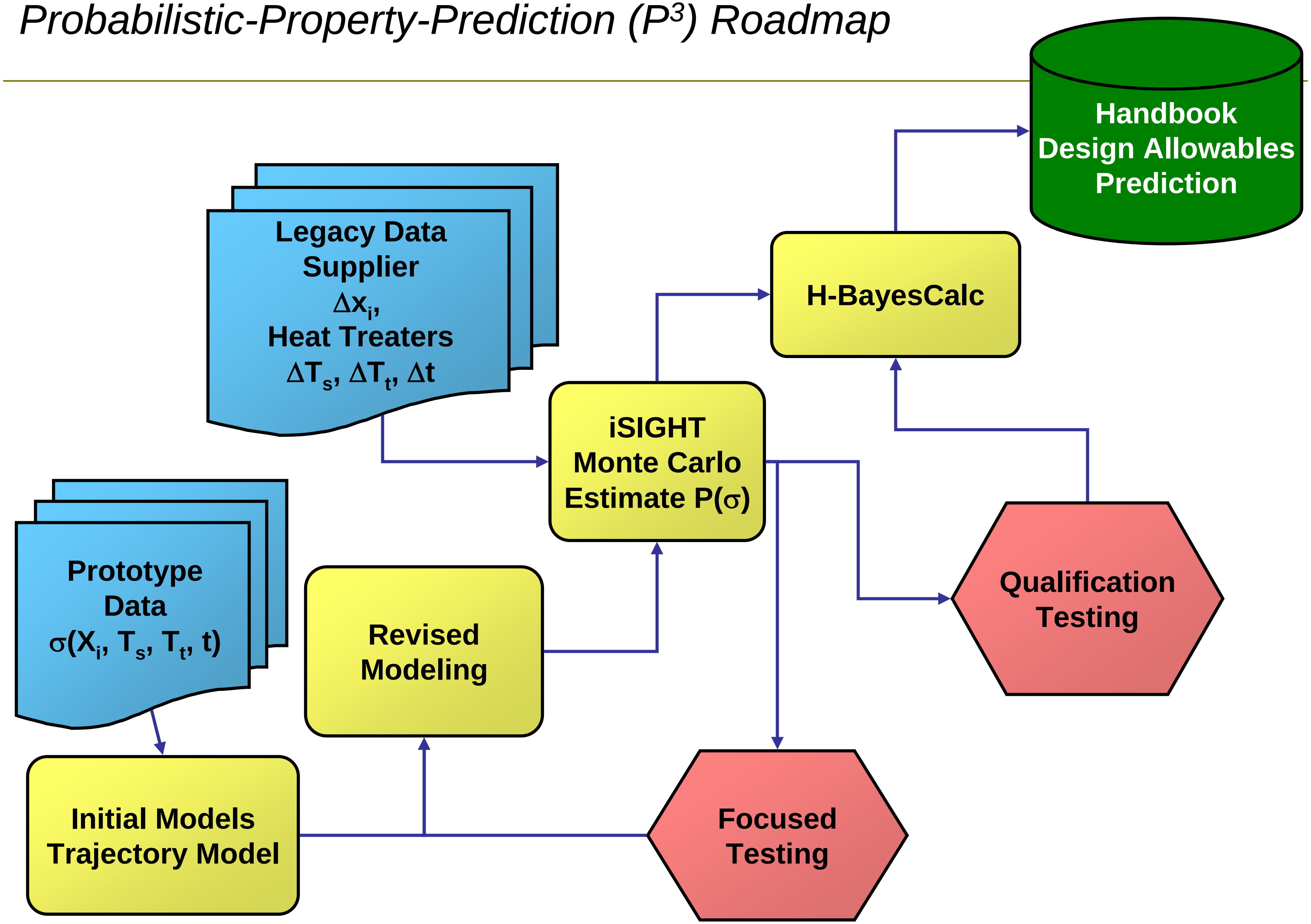
Probabilistic-Property-Prediction (P^3) Roadmap



S53 Robust/Sensitivity Analysis with Compositional Variations

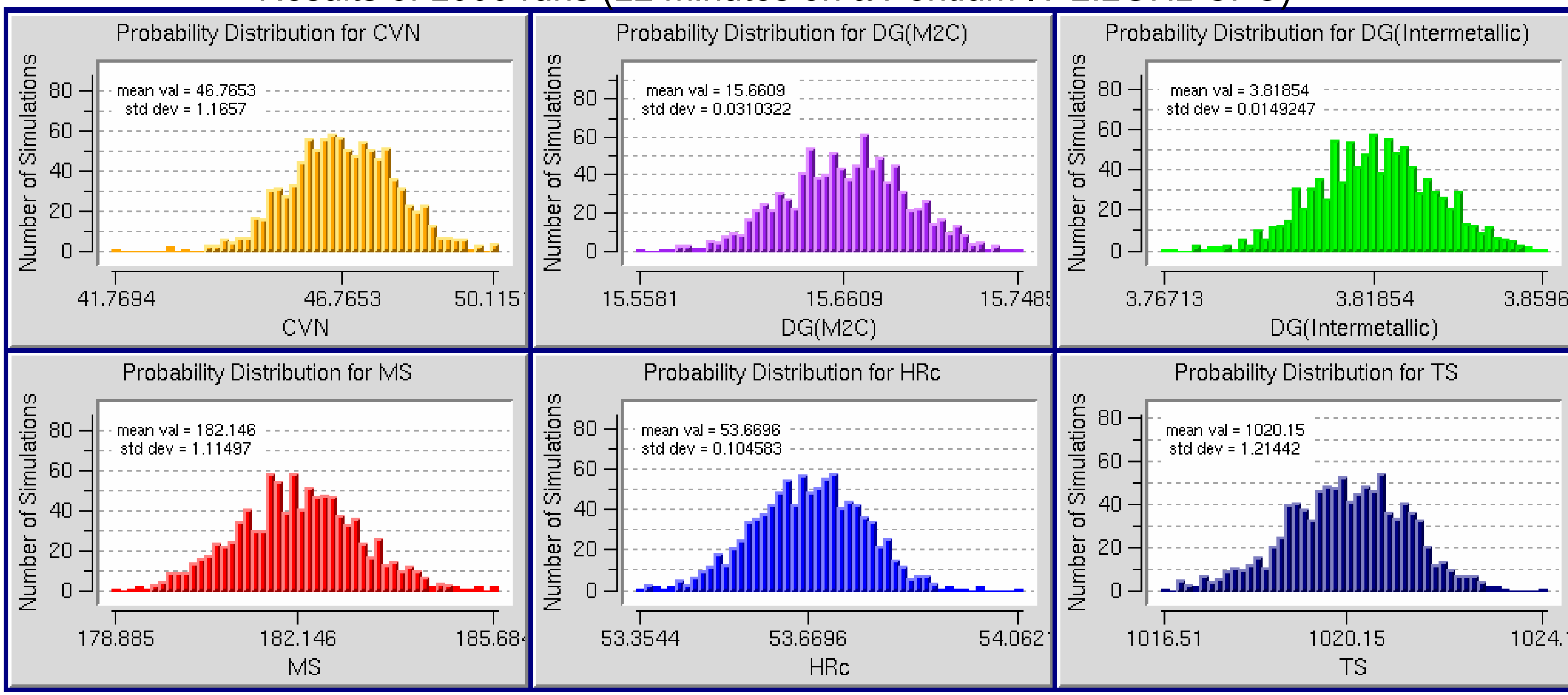
Compositional Variations (wt%, $\pm 6\sigma$):

C	$\pm$ 0.01	Cr	$\pm$ 0.2	Mo	$\pm$ 0.1
W	$\pm$ 0.1	Co	$\pm$ 0.3	Ni	$\pm$ 0.1
V	$\pm$0.02				

CMD/ iSIGHT

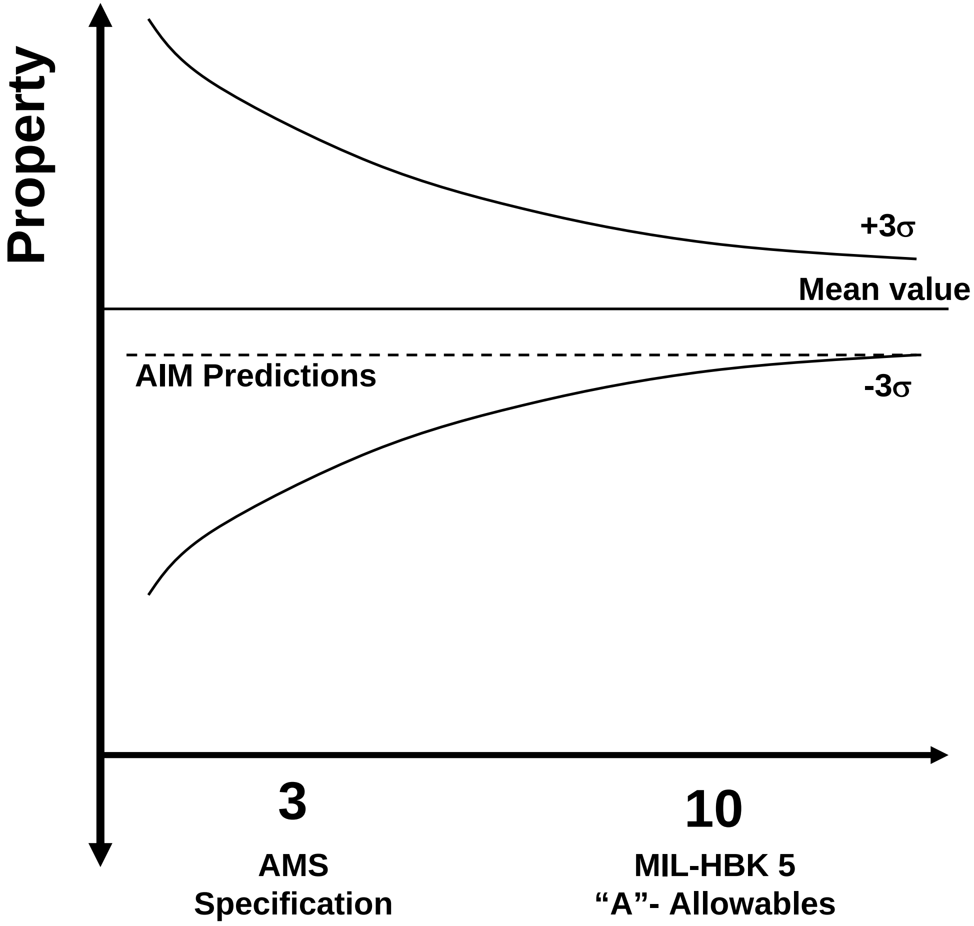
Variations of:
Structure — carbide solvus Ts, martensite Ms, precipitation control ΔG's
Property — hardness HRc, toughness CVN

Results of 1000 runs (12 minutes on a Pentium IV 2.2GHz CPU)



ESTCP AIM Objectives

- Objective is to predict MIL-HBK 5 “A”- Allowables with only 3 heats available.
- Designers can design new LG components with confidence 3-5 years earlier.
- Testing costs are 70% lower, overall costs are 50% lower.



Summary and Takeaways

- S53 has demonstrated property goals in multiple production scale heats.
- Primary manufacturing evaluations have been completed for machining, surface treatments, and welding.
- Yield stress is the property most sensitive to process variation.
- AIM methods will predict MMPDS (MIL-HNBK-5) A-allowables with 3 heats completed.
- First applications to be completed for Air Force replacement requirements. A-10, 2007-2008